Workshop on the Impacts of Aviation on Climate Change

Don Wuebbles
Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign
Urbana, IL 61802

Mohan Gupta
Office of Environment & Energy
Federal Aviation Administration
Washington, DC 20591

Malcolm Ko
Science Directorate
NASA Langley Research Center
Hampton, VA 23681-2199

ABSTRACT

Projections indicate that demand for aviation transportation will increase by more than two fold over the next few decades. Timely action is needed to understand and quantify the potential climate impacts of aviation emissions particularly given the sustained lapse over the last several years in U.S. research activities in this area. In response to the stated needs, a group of international experts participated in the "Workshop on the Impacts of Aviation on Climate Change" during June 7-9, 2006 in Boston, MA. The workshop focus was on the impacts of subsonic aircraft emissions in the UT/LS region and on the potential response of the climate system. The goals of the workshop were to assess and document the present state of scientific knowledge, to identify the key underlying uncertainties and gaps, to identify ongoing and further research needed, to explore the development of climate impact metrics, and to help focus the scientific community on the aviation-climate change research needs. The workshop concluded that the major ways that aviation can affect climate, in agreement with the 1999 assessment by the Intergovernmental Panel on Climate Change (IPCC), are the direct climate effects from CO_2 and water vapor emissions, the indirect forcing on climate resulting from changes in the distributions and concentrations of ozone and methane as a primary consequence of aircraft nitrogen oxide (NOx) emissions, the direct effects (and indirect effects on clouds) from emitted aerosols and aerosol precursors, and the climate effects associated with contrails and cirrus cloud formation. The workshop was organized in three subgroups: (1) Effects of aircraft emissions on the UT/LS chemical composition, (2) Effects of water and particle emissions on contrails and on cirrus clouds, and (3) Impacts on climate from aircraft emissions and identification of suitable metrics to measure these impacts.

The workshop participants acknowledged the need for focused research specifically to address the uncertainties and gaps in our understanding of current and projected impacts of aviation on climate and to develop metrics to better characterize these impacts. This may entail coordination and/or expansion of existing and planned climate research programs, or new activities. Such

efforts should include strong and continuing interactions among the science and aviation communities as well as policymakers to develop well-informed decisions.

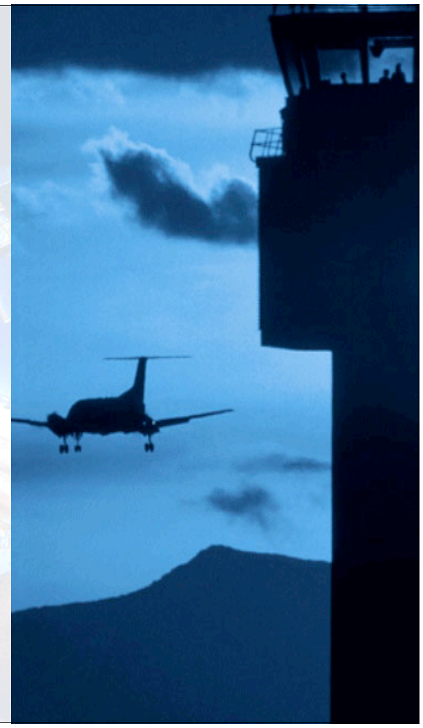
Workshop on the Impacts of Aviation on Climate

Don Wuebbles
University of Illinois
Urbana, Illinois 61801

Mohan Gupta
FAA

Malcolm Ko
NASA Langley

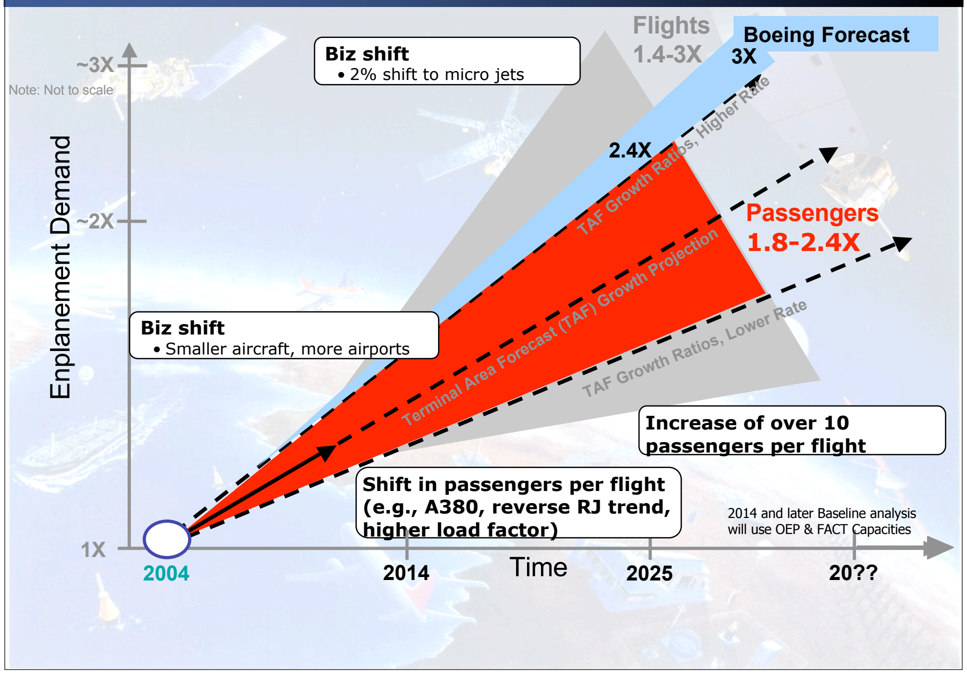
December 12, 2006



Aviation and Climate

- Aviation plays a key role in the world and US economies
  - Aviation supports 8% of global economic activity and carries 40% of the value of freight
  - U.S. has 4% of world’s population and 40% of aviation activity
  - Aviation activity outpaces economic growth
- Aviation 2-3% of global GHG emissions
- Aviation is still 5th largest contributor to GHG in EPA inventories and a key source in UNFCCC nventories
- Aviation may grow as a climate contributor in context with other sources

Future U.S. Aviation Services Demand



Aviation and Climate Change

Climate change impact is potentially the most serious long-term issue facing the aviation industry

"Further work is required to reduce scientific and other uncertainties, to understand better the options for reducing emissions, to better inform decision-makers, and to improve the understanding of the social and economic issues associated with the demand for air transport."

Aviation and the Global Atmosphere, IPCC (1999)

"The (environmental) topic of greatest uncertainty and contention is the climate impact of aircraft."

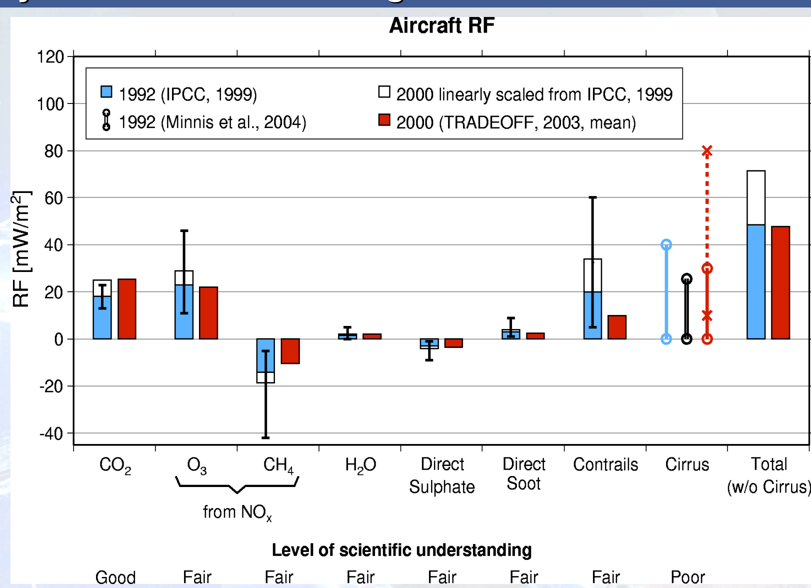
Aviation and the Environment, Report to the US Congress (2004)

The Challenge: understand and address the effects on climate resulting from aircraft engine emissions

Most emissions occur at cruise altitudes in the UT/LS

- **Direct effects of carbon dioxide (CO2) emissions Indirect effects from changes in ozone and methane from NOx emissions**
  - **At these altitudes, NOx emissions produce O_3**
  - **Increase in ozone results in increased tropospheric OH and reduced CH_4**
- **Indirect effects from water vapor and particle emissions due to contrail formation and corresponding effects on cloudiness**
- **Direct effects from aerosols (particles) either emitted directly (e.g., soot) or produced from emitted precursor gases (e.g., SO2)**
- **Direct effects from water vapor emissions in stratosphere**

Analyses of Radiative Forcing from Subsonic Aircraft



Radiative Forcing quantifies the change in global radiative energy balance attributable to each emission.

Several Take Home Messages

- Time scales of climate effects after emission
  - CO_2 effects are for many decades (τ ~ 100 yrs)
  - Other emission effects much shorter
    - O_3 : 1-2 years or less
    - CH_4: ~10-12 years (but only get full effect if NOx emitted for >10 yrs)
    - Particles: < 1 year
    - Contrails: days to months
- Particles can have direct climate effects and indirect effects by acting as cloud condensation nuclei
  - Indirect effects may dominate
- Except for the CO_2 effect, large uncertainties remain

Workshop Objectives

- **To assess and document**
  - **The current state of knowledge**
  - **Uncertainties and gaps**
- **To identify**
  - **Ongoing research to constrain the uncertainties and fill the gaps**
- **To recommend**
  - **Prioritized short- and long-term future research needs**
- **To help focus the scientific community on aviation-climate change research needs**

This workshop is the first such U.S. (and even international) effort since the IPCC 1999 report on Aviation and the Global Atmosphere.

Workshop Details

- June 7-9, 2006
- Sponsors: FAA, NASA, PARTNER Center of Excellence, JPDO
- Workshop chaired by Prof. Donald Wuebbles (UIUC)
- About 35 international science experts from the U.S., Europe (UK, Norway and Germany) and Canada
- Federal research, university and industry representation
- Three science focus groups
- Participant authored workshop report; externally reviewed

This report can be downloaded at:
http://web.mit.edu/aeroastro/partner/reports/climatewrksp-rpt-0806.pdf
or
http://climate.volpe.dot.gov/docs/aviationclimwkshp.pdf

Workshop Focus

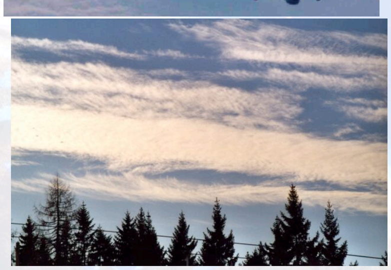
- Emissions in the UT/LS region and resulting chemistry effects
  Subgroup led by Dr. Anne Douglass (NASA GSFC)
- Contrails and induced cirrus clouds
  Subgroup led by Dr. Kärcher (DLR, Germany)
- Climate impacts and climate metrics
  Subgroup led by Dr. W.-C. Wang (SUNY-Albany)
- Climate impact tradeoffs
  All subgroups addressed

Key Findings and Research Needs – Subgroup 1

- Emissions in the UT/LS region and resulting chemistry effects
  - Models have improved representation of chemical and physical processes since IPCC (1999)
  - Need models and measurements intercomparison to evaluate uncertainties;
  - Need new measurements and data analyses to improve understanding of troposphere and UT/LS processes
  - Need new evaluations of emissions
    - Better account for real flight characteristics
  - Re-examine the impacts of aviation using improved models

Key Findings – Subgroup 2

- Contrails and induced cirrus clouds
  - Basic physics of contrail formation reasonably well understood, but important parameters (e.g., temperature, humidity in UT, optical properties) remain uncertain.
  - There remain significant issues with the scale of climate models versus the size of the plume
  - Aviation-induced persistent contrails and aerosols may affect cirrus, but poorly understood.



Key Research Needs – Subgroup 2

- Contrails and induced cirrus clouds -- Research
  - Regional studies of supersaturation and contrails using measurements and weather forecast models;
  - *Need In situ* probing and remote sensing of aging contrail-cirrus and aircraft plumes;
  - Global model studies addressing direct and indirect effects of contrails and effects on cirrus;
  - Enhanced analysis of existing or upcoming information from space-borne sensors;
  - Process studies of plume and contrail development;
  - Laboratory measurements of ice nucleation

Key Findings and Research Needs – Subgroup 3

- Climate impacts and climate metrics
  - Some metrics for aviation effects on climate are being used.
  - Radiative forcing (RF) needs to include efficacy for various climate effects, but RF not an emissions based metric. Need emission based metrics (e.g., GWPs)
  - Identify, develop and evaluate metrics for climate impact assessments and examine scientific basis;
  - Quantify the uncertainties in proposed metrics;
  - Need better understanding of the climate effects from contrails and cirrus;
  - Systematic model intercomparison of efficacy studies and climate effects.

Key Research Needs – Aviation Tradeoffs

- Aviation emissions tradeoffs (within climate impacts)
  - Need sensitivity analyses for various trade-offs
    - Emission reduction vs. fuel technology
    - Flights re-routing (altitude as well as latitude)
    - Geographical distribution of aviation
    - Differential impact of day/night operations
    - Co-dependence of physical impacts – how future climate change may alter aviation impacts

Trades between noise *vs.* emissions impacts (and amongst emissions) also part of tradeoffs but workshop participants not charged to address them – however, FAA and the international community must address these issues.

Workshop Recommendations

"… the need for focused research efforts in the U.S. specifically to address the uncertainties and gaps in our understanding of current and projected impacts of aviation on climate and to develop metrics to characterize these impacts."

"… coordination and expansion of existing and planned atmospheric and climate research programs or development and implementation of new aviation focused research activities."

"… a strong interaction between science and aviation communities while undertaking such initiatives."

FAA and other agencies are working with the science community to prioritize research needs and establishing research support.

EXTRA SLIDES

No Simple Solutions: Consideration of Trade-offs

Continuous Descent Approach
- Reduced **Noise**
- Reduced **Fuel Burn/CO_2**

Reduce cruise altitude
- Increased fuel burn, **CO_2**
- Increased **NO_x**
- Less increase **O_3**
- Reduced **contrails**

Operations changes
- Reduce **contrails**
- More **fuel burn, CO_2**

Nacelle Modifications
- Reduced **Noise**
- Increased **Fuel Burn/CO_2**

Improved aerodynamic efficiency and reduced weight
- Reduced **CO_2**
- Reduced **Noise**
- Reduced **NO_x**

Reduced polar flights
- Less effects on stratosphere
- More **fuel burn, CO_2**

Steep climb
- Reduce **noise**
- More **fuel burn, CO_2**

Increased Engine Pressure Ratio & Temperatures
- Reduced **Fuel Burn / CO_2**
- Reduced **HC** and **CO**
- Increased **NO_x**

Increased engine bypass ratio
- Reduced **Fuel Burn / CO_2**
- Reduced **Noise**
- Increased **NO_x**